



**A COST ASSESSMENT OF THE DAYTON
PUBLIC SCHOOLS VEHICLE ROUTING
PROBLEM**

THESIS

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ABSTRACT

The routing and scheduling problem involves both constructing efficient routes to deliver goods or services to and from customers from a single depot or set of depots, as well as scheduling particular vehicles to these routes such that customers receive their goods within a specified time window. There have been several different methods developed to reduce the costs incurred in transporting goods or services (i.e. students) to customers (i.e. schools). This problem may be used to model many circumstances in logistics and public transportation.

Several school districts do not utilize operations research techniques to minimize, as much as possible, the costs associated with the operation of its pupil transportation system. In contrast, Dayton Public Schools (DPS) employs the optimization software package VersaTrans to minimize its transportation expenses. However, due to the importance it has placed on customer satisfaction, DPS has ultimately been reduced to door-to-door pickups. This, combined with an open enrollment policy and higher fuel prices, has resulted in an explosion of transportation related costs. Though DPS has made many great strides to gain control of its spending, due primarily to better management, there is still much to accomplish. This thesis seeks to utilize the VersaTrans routing software available to the Dayton Public School district to construct efficient routes that are feasible under a consolidated bell schedule so that both bus usage and route times are minimized.

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Frankie L. Woods

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A COST ASSESSMENT OF THE DAYTON PUBLIC SCHOOLS VEHICLE ROUTING PROBLEM

I. INTRODUCTION

Minimizing the costs associated with school bus routing is a common problem faced by logistical planners in today's resource constrained world. In fact, over a hundred firms offer proprietary software to aid school districts in that exact endeavor. With rising fuel costs and a deep economic recession looming, school districts across the nation are, more than ever, being forced to find ways to cut costs in their operations, while continuing to provide children with the quality education they will need to compete in an increasingly global market. One of the more obvious potential sources for savings can be found in transportation, specifically with routing and scheduling.

According to a report to Congress by the National Highway Traffic Safety Administration, as of November 2008, twenty-six million children travel over four-billion, four-hundred thousand miles on five-hundred thousand school buses each year. This equates to approximately fifty-three percent of all K-12 students in the country riding yellow school buses, with each bus carrying roughly fifty-four children (27). Each of these children is assigned to one of the thousands of school districts scattered across the United States. The pupil apportionment is based primarily upon where that student resides. It is generally the responsibility of each district to provide transportation to and from school for students within its locality. However, it has become increasingly

common to place that responsibility in the hands of the parent, as is currently observed with the Dayton Public School's (DPS) high school students.

It is often assumed that bus routes and schedules can be planned quickly and efficiently because the location of each bus stop; the demand, or number of students per bus stop; and school start and release times are all known in advance (Spada et al., 2008). However, vehicle routing is often intractable in large instances due to the inherent difficulty associated with these types of combinatorial optimization problems.

The school bus routing and scheduling problem involves both constructing efficient routes to deliver students to and from school from a set of aggregated bus stops, as well as scheduling particular buses to these routes such that students are dropped off and picked up from school within a specific time window. There have been several different methods developed to reduce the costs incurred in transporting goods or services (i.e. students) to customers (schools). Solving these problems to optimality using some form of integer programming is often extremely difficult due to the nature of the problem, especially when dealing with large school districts that transport thousands of children. The use of heuristics has increasingly improved one's ability to find optimal or near optimal solutions. However, the idea of solving the routing and scheduling problem simultaneously adds a great deal of complexity and has yet to be thoroughly explored thru detailed research, outside the professional community whose primary interest is to produce proprietary software to sell to these beleaguered school districts.

1.1 Background

Like many districts around the country, the Dayton Public School District (DPS) is entrusted with the responsibility of transporting thousands of children to and from its

several schools each day. It is, in fact, one of the most complex processes the district faces. It involves meeting national, state, and regional safety guidelines; satisfying parent concerns; and minimizing the total cost incurred by its operations. In the case of DPS, the school board's biggest limitation to efficient routing comes from the importance it places on customer satisfaction.

As mandated by the Ohio Pupil Transportation Operations and Safety Rules (2008), transportation services are offered to eligible students who live within the boundaries of the district and attend DPS schools, as well as students, who live within the district boundaries but attend non-public, charter, and non-parochial schools that are within thirty minutes of the student's residence/stop. DPS is conscious of the "Safety First" concept, preventing school buses from operating in certain conditions, and providing instructions on how to correctly pickup and drop off students. There are no official guidelines that limit the amount of time that students may ride school buses, but DPS attempts to keep routes to a maximum length of sixty minutes. These guidelines affect the travel time of each bus per route, given a particular number of stops. All currently serviced routes meet or exceed local, state, and national statutes and regulations.

Transportation is offered daily, on a single round-trip basis. They are intended to serve the maximum amount of students and keep the trips as short as possible. Students that fall within the DPS jurisdiction are assigned to Board-approved bus stops. This typically involves picking up each child at his or her home. Special "bus stops" are created for children that live in cul-de-sacs, due to the inherent difficulty that buses have in negotiating them.

1.2 Motivation

DPS currently operates one-hundred and ninety-seven buses and travels twenty-three thousand miles a day. Operating costs exceed thirteen million dollars annually. Surprisingly, fuel represents just 15% of those expenditures, at two million dollars. DPS serves approximately twenty-six thousand students daily, twelve-thousand of which require public transportation. The capacity of each bus averages sixty-six passengers for elementary students and forty-four passengers for middle and high school students. The difference in capacity is associated with the different sizes of the students. Hence, the buses can not necessarily be looked at as a homogeneous fleet unless the problem is partitioned by student type.

Interestingly, just fifty miles south, the Cincinnati Public School District (CPS) serves thirty-one thousand children, almost 3.5 times as many students as DPS. However, CPS travels just 1.22 times more miles (twenty-eight thousand ninety-nine miles) and uses just 1.64 times more buses (three-hundred and twenty-four buses). CPS also manages to operate on a budget that is nearly three million dollars less than that of DPS, running in the order of roughly ten million dollars annually (9). This comparison illustrates the potential savings that may be generated by devising a more efficient scheduling and routing scheme for DPS. That information may motivate the Dayton school board to make some currently unpopular political decisions, while strictly adhering to child safety issues, in dealing with school bus routing and scheduling.

DPS has access to routing and scheduling optimization software entitled VersiTrans. It is actually a common practice for districts around the nation to purchase readily available routing software to help reduce transportation costs. In fact, it has been

shown that savings of between 5 and 30% can be gained by using some computer-based routing and scheduling system. However, most districts generally ignore the capabilities of the software and build routes by hand because they either lack the training necessary to effectively use the program or distrust its validity (Bodin et al., 1979). DPS, on the other hand, uses the optimization software to initially build its routes. Nevertheless, implementing a program based on curb-to-curb pickups severely limits the usefulness of the program by not instituting optimally located bus stops across the region. In addition, it is not unusual for there to be over thirty changes to bus routes and schedules each day due to student relocation, as well as the constant flux of parent and student demands around the district (i.e. bullies, walking distances, etc.). These additional transportation requests, whose satisfaction are not required under the Ohio Pupil Transportation Operations and Safety Rules (2008), may be the primary cause of buses in the district running under 70 percent capacity.

VersaTrans provides data on the number of routes in use, the number of buses used, the distance traveled by each bus, and the amount of time it takes each bus to traverse a particular route. It also contains the home address and bus stop location for each of the students in the district that are riders. Therefore, the data exists to assess the current operating costs associated with the transportation of students in the DPS district based on different potential routing scenarios.

1.3 Problem Statement

The research documented in this thesis was sponsored by the Dayton Public Schools (DPS) Transportation Community Collaborative. The responsibility of DPS is to provide safe and efficient transportation to as many of its city pupils as possible. In order

to provide quality customer service, however, the ability to maintain efficient routes has become a distant thought. In an effort to get back to the basics of its operations, DPS decision makers have come together to unearth efficiency improvement opportunities that may exist within its enterprise.

The main thrust of this thesis is to investigate the routing and scheduling of DPS yellow school buses for kindergarten thru eighth grade students. Specifically, the research examines the potential savings that may be available through streamlining and/or consolidating bus routes. DPS policy states that, excluding extenuating circumstances, it will not provide transportation to students within a two-mile radius of their intended school, nor will it alter bus schedules and routes to meet individual family circumstances. Nevertheless, exceptions are so commonplace that DPS has essentially been reduced to, as the industry describes, “curb-to-curb” pickups. This means that DPS is adding bus stops in such a fashion, that Dayton pupils are being served at their doorsteps.

1.4 Research Contributions

The main intention of this research is to illustrate the savings that may be revealed by instituting neighborhood or “straight line” bus stops. Straight line stops are those placed on main roads that have been designated safe by DPS officials. As discussed by Bodin et al. (1983), a source of considerable savings will come from parting with the door-to-door student pickup methodology and establishing centralized “ministops” that students must walk to. Once in place, the research uses the VersaTrans optimization/heuristic software to route students by way of these stops. VersaTrans serves as the primary optimization software used to develop routes in an attempt to

change the way DPS conducts business. Once routes are constructed, an optimal bell schedule is developed to minimize the number of buses required. In this way, a process for building cost effective routes can be instituted which is transparent and repeatable. The biggest hurdle in dealing with DPS consists of ensuring that the savings recouped in implementing the new transportation methodology justify the potential reduction in customer satisfaction.

1.5 Thesis Organization

The remainder of this thesis is organized as follows. Chapter II reviews the literature pertinent to this topic. Chapter III is organized as a stand-alone article to be used as a submission to an academic journal. Chapter IV provides a more detailed look at the results from the test scenarios. Chapter V concludes the research and provides possible areas for further research and application of this topic.

II. LITERATURE REVIEW

2.1 The Scheduling Problem

Scheduling is a managerial process that is instrumental in many transportation and distribution settings. Typically, the schedule adopted by an organization will have major impacts to the organization's performance. Scheduling is defined as allocating scarce resources to tasks over time (Pinedo, 2005). In the case of school buses, it specifically deals with assigning particular buses to routes.

Ample attention has been given to school bus scheduling in the past. Angel et al. (1979), Bodin and Berman (1979), Chen et al. (1988), and Swersey and Ballard (1984) have all developed approaches to determine bus schedules. School bus scheduling is regarded as more important than the Vehicle Routing Problem (VRP) when considering their effective utilization in an urban setting (Bodin et al., 1979). The reason behind this is that a single bus in a fleet can run many routes in a day. Thus, effective scheduling will greatly reduce the number of buses needed by the district. Once the routing component is complete, the student loads on each of the routes are no longer constraints in the scheduling component. The problem of simultaneously solving the school bus routing and scheduling problem can now, therefore, be avoided because we need only construct a minimum number of routes and then expertly schedule buses to them. If one is permitted to change the starting and ending times of the schools in a school district to reduce the number of students traveling during peak times, then an overall reduction in the number of buses needed can be realized (Bodin et al., 1979).

In some cases, it is acceptable to assume that the starting and ending times of all schools in the district are known. Though a bell schedule is in place for DPS, this research aims to improve upon that schema after more efficient routes are created. A method is fashioned by which the routes can be partitioned into distinct periods. It is also often assumed that each bus services at most one route each time period. Under these assumptions, the period of most interest will be during peak operating hours. Buses may be idle or inefficient in off peak periods because the objective function has more of an emphasis on reducing travel time. During the busiest time interval, DPS utilizes the most buses. A reduction in the number of buses used during this period will result in an overall reduction in the number of buses needed on hand. One simple method of meeting that goal is to ensure that there are no idle buses during that time such that an optimal or near optimal solution is obtained when constructing a bus schedule (Bodin et al., 1979).

2.1.1 Computer-Based Scheduling Methods

Many scheduling techniques exist for school districts to exploit in their cost saving endeavors. In most instances, data must first be fed in from the routing phase. In one example, Angel et al. (1972) use a modified Moore algorithm to produce the time and distance matrix required by the scheduling phase. The matrix contains the shortest path in time between any pair of bus stops, the quantity and capacities of buses, maximum route time in minutes, loading time per student, and allowance for extra time at each stop. The authors explain that the objectives of bus scheduling is to obtain a bus loading pattern that minimizes the number of routes and mileage per bus; avoids overloading all buses; and prevents the time required to traverse any route from exceeding the maximum allowed by policy (Angel et al., 1972). The last objective is

introduced because the prime concern of the school district is safety. By ensuring that route loads and route driving times are balanced, bus overloading is avoided and reasonable student riding times are maintained.

Swersey and Ballard (1984) use linear programming relaxations of the original integer programs to solve seventy-five percent of problems encountered. They ignore the routing element of school bus routing and scheduling problems all together and concentrate solely on the intricacies of scheduling. As in Bodin and Burman's (1979) procedure, Swersey and Ballard (1984) allow for time windows rather than requiring fixed arrival times. This establishes an increased number of feasible links between routes, reducing the number of buses required. They consider only the morning problem because, after minor adjustments are introduced, the afternoon problem will be similar. This is because the afternoon school end times are more detached than the morning start times. Thus, the morning problem will tend to have a peak operating time that will require as at least as many buses as the afternoon problem.

To obtain an optimal solution using mixed integer program, Swersey and Ballard (1984) do not partition school start times. This differs from the heuristic approximation approach employed by Bodin and Burma (1979). Swersey and Ballard's (1984) procedure to solve the integer program is as follows: relax and solve the integer program; continue to add a constraint that the number of buses be equal to the smallest integer greater than the previous objective function value and re-solve the LP until an integral solution (the number of buses required) is acquired.

Angel et al. (1972) use constant loading times and driving speeds in their algorithms. Swersey and Ballard (1984), conversely, use Euclidean distances, which

closely approximate the actual travel distance, to estimate the travel distance between the ends of routes and schools. Translating travel distances to travel times by assuming constant travel speeds along routes and from schools to endpoints of routes provide good estimates. If buses are required to stop more often (i.e. in an urban setting such as seen at DPS), then starting and stopping times become important because travel times are generally not related to the number of bus stops (Angel et el., 1972; Swersey and Ballard, 1984).

2.2 Vehicle Routing Problems

The Vehicle Routing Problem (VRP) is a complex combinatorial optimization problem that has challenged operational researchers for more than 40 years. Introduced by Danzig and Ramser in 1959, this NP-Hard problem can be described by combining two well known problems: the Traveling Salesman Problem (TSP) and the Bin Packing Problem (BPP) (Ralphs, 2003). The VRP has a plethora of real world applications, which has sparked much interest over the past several decades. Angel et al. (1979), Bodin and Berman (1979), Chen et al. (1988), Cordeau (2006), Ralphs (2003), and Repoussis (2007) have each approached routing in various ways.

The Capacitated Vehicle Routing Problem (CVRP) is the most general version of the VRP (Machado, 2002). It can be formulated by designing an optimal set of minimum cost routes for a fleet of k independent, homogeneous vehicles originating at a common depot, 0 , and servicing the demands, d_i , of n customers (schools/students). The routes must be designed such that each point is visited only once by exactly one vehicle, all routes start and end at the depot, and the total demands of all points on one particular route cannot exceed the capacity of the vehicle. The cost is determined by c_{ij} , the

distance from customer i to customer j . The distance between customers is symmetric, i.e. $c_{ij} = c_{ji}$, and $c_{ii} = 0$. A graphical representation is presented in Figure 1, where the nodes represent customers and arcs represent routes.

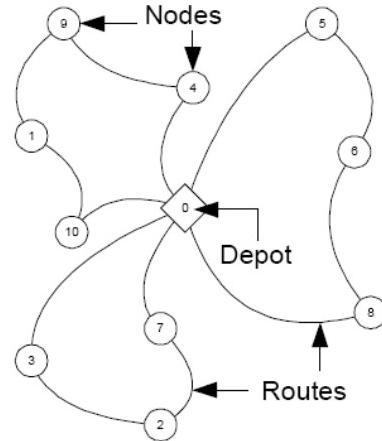


Figure1: Vehicle Routing Problem

In application, the size of the problem instance generally becomes much too large to solve with typical integer programming methods. Most approaches for the VRP rely on heuristics to generate near optimal solutions in a reasonable amount of time (Machado et al., 2002).

To accurately apply the practical application of the VRP to school bus routing, it must be manipulated in various ways. Bodin et al. (1979, 1983) provides a detailed depiction of the many nuances that are associated with this problem. It is first necessary to partition subsets of the bus stops under the school district's jurisdiction by school. Each of these bus stops will have students assigned to them. Timing restrictions (time windows) must also be incorporated into the vehicle dispatching model to account for the requirement that buses must pickup students within a certain time frame. These windows relate to district bell schedules that exist, dictating the fixed starting and ending times for

each school within the region. The time windows, which correspond to the bell schedule, shape the time intervals allowed for the pickup and delivery of the students to and from their respective schools. The system is constrained so that each student must be picked up at or dropped off at his home or school on schedule.

In order to construct a set of minimum cost routes for the district's fleet, the objective is defined as minimizing the fleet's operating cost and the number of vehicles used. Since there has not been much research conducted in the combined routing and scheduling problem, it is customary to break it down into three parts: selecting the starting and ending times of the schools, building partial vehicle routes, and forming daily bus schedules (Bodin et al., 1983). It is generally assumed in much of the literature that the fleet is a homogenous fleet with identical capacities which carry identical goods. As assumptions change, the problem instance becomes much more intractable as several additional variables and constraints are introduced to the formulation.

2.2.1 Computer-Based Routing Techniques

The purpose of an automated school bus routing and scheduling system is not only to minimize the transportation costs incurred by the school district in question, but also to minimize the average transportation time of each student and, most importantly, provide an automated procedure for setting up daily schedules for the fleet (Bodin et al., 2001). There are several methods available to analysts and institutions to create routing programs.

Bodin et al. (1979) and Chen et al. (1988) use the Dijkstra algorithm to generate the matrix of shortest travel times from a school to all bus stops. Chen et al. (1988)

executes the algorithm only once, storing the resultant shortest path in the knowledge base. Zeng et al. (2007) uses the crossing method to solve the NP hard routing problem.

Zeng et al. (2007) also use the widely known Clarke and Wright (1964) heuristic to construct the initial solution to be used in the GC method. The authors introduce the annealing-based GC method to reduce the possibility of the GC method getting trapped at local optima. It involves a generalization of the normal string crossover operator, in which new routes are constructed not only by combining the strings in their original direction but also by combining the strings with the opposite direction. The results of the GC method used on Christofieds (1979) Euclidean VRP instances perform well, but more research is needed to test the method on other types of VRP (Zeng et al., 2007).

The open vehicle routing problem with time windows (OVRPTW) is introduced by Repoussis et al. (2007). It seeks to efficiently employ a set of capacitated vehicles such that a set of non-depot returning vehicles routes satisfy customer requirements within fixed time intervals which represent the allowable period the customer's service can take place. The OVRPTW is a special case of the well known VRPTW presented by Cordeau et al (2001). Open vehicle routing problems are faced by companies which are required to contract external vehicle services to deliver some or all of their goods. Companies often will hire outside help if they do not have the appropriate fleet or want to avoid the costs associated with maintaining one (Tarantilis et al., 2004). DPS currently owns and operates its entire fleet, but the OVRPTW could be a good option if maintenance costs become cumbersome.

The OVRPTW covers three types of subproblems: delivery, pickup, and both delivery and pickup. The DPS problem is most closely associated with the delivery and

pickup sub problem. After finishing all morning pickups and dropping off all students at their respective schools, the buses will return to the central depot. The buses will later revisit each school in the afternoon and follow their respective morning pickup routes in reverse order. Repoussis et al. (2007) note that, though the time window constraints do not allow a vehicle to service a customer before its time window interval, a vehicle can arrive before the lower bound and idle until the allowable service time begins. The heuristic investigated in the paper is classified as a route-construction insertion-based sequential approach. The results of the approach provide high-quality solutions, which reinforce the belief that exploiting to a large extent the time window-based information results in high-quality solutions (Repoussis et al., 2007).

Bodin et al. (1983) mention that the Dial-a-Ride problem may be suitable for the bus scheduling and routing problem. Cordeau (2006) presents a paper for designing a set of minimum cost vehicle routes satisfying capacity, duration, time window, pairing, precedence, and ride-time constraints. The aim is to design a minimum-cost set of vehicle routes accommodating all requests, where the objective is to minimize operating costs (fleet size and distance traveled) while also minimizing user inconvenience (deviations from desired pick-up and drop-off times and excess ride times).

The pickup and delivery problem with time windows (PDPTW) may also be adapted to suit the purposes of bus routing. As explained by Ropke and Pisinger (2006), PDPTW consists of a number of requests and vehicles. A request consists of picking up goods at one location within a specified time window and delivering these goods to another location within a second time window. There are also service times associated with each pickup and delivery, which indicate how long it will take for the pickup or

delivery to be performed. For DPS, these service times represent the time it takes to load and unload students, and the time window indicates when a student at a particular location must start. The start and end locations do not need to be the same, as will be the case for DPS. It is possible to have vehicles end at different terminals, but DPS maintains a central depot for storing and servicing its buses. A route is valid in PDPTW if time windows and capacity constraints are obeyed along the route, each pickup is served before the corresponding delivery, corresponding pickup and deliveries are served on the same route, and the vehicle only serves requests it is allowed to serve (Ropke and Pisinger, 2006). The problem objective consists of minimizing a weighted sum: the sum of the distance traveled by the vehicles, the sum of the time spent traveling by each vehicle, and the number of requests that are not picked up and delivered. The third objective does not make much sense in the DPS case because, due to its strict adherence to child safety, it cannot afford to miss a child for any reason. The mathematical model is based on a model proposed by Desaulniers et al (2002) as well as the Large Neighborhood Search (LNS) introduced by Shaw (1997).

A determination as to what capacity and time constraints will be used when applying one's procedure to an actual case must also be considered. Angel et al. (1972) use a capacity constraint of seventy-two passengers and the time constraint set to 70 minutes. This allows for a ten percent overload, accounting for absenteeism and self transportation means that sometimes occur on a normal school day. However, this may be a poor assumption when considering child safety as it relates to overloading. Chen et al. (1998) offers similar rules for planning routes. Though the introduced routing techniques are applied to a rural county school district in Alabama, making many of the

assumptions invalid for the DPS case, it does institute road condition constraints which differ from much of the literature. Their assumptions are as follows: pupil riding times should not exceed a prescribed limit (i.e. 60 minutes), bus loads should not exceed bus capacity (including absenteeism), pupils should arrive at their schools within a prescribed period, the pupils who live within a certain distance (i.e. 2 miles) from their schools will be transported only when they live on existing routes and there are seats available, distance between two bus stops should exceed a certain limit (i.e. 0.2 miles, hence no door-to-door stops), the number of buses should be as few as possible, the fleet travel distance should be as small as possible, and the fleet student-miles should be minimized. The authors state that the bus should also travel “express” to the school via the shortest route if either the capacity, or the cumulated travel time tends to exceed the maximum allowable riding time.

2.3 Proprietary School Bus Routing and Scheduling Software

If one conducts a simple Google search for school bus routing, over a hundred sites are found advertising proprietary software. InterGis, Fleet Matics, VersaTrans, Express Technologies, and Orbit Software are just a few of the more prominent businesses offering their services.

One must be careful, however, about the ad hoc purchase and implementation of packages picked off of the shelf. Many of these systems either do not involve the user or veteran route designer in the solution process, or do not provide the necessary knowledge behind the algorithms involved (Chen et al., 1988). Additionally, many of these algorithms do not account for non-quantifiable factors such as safety, preference, and judgment. Assumptions may, for example, be fuzzy and not uniform, constraints may be

soft as opposed to rigid, and the objectives may be to simply satisfy, rather than optimize, certain criteria (Chen et al., 1988). Therefore, it is important to pick software that has been developed with an expert system approach by which the expert knowledge of the problem is kept separate from the solution execution (i.e. road maps, school locations, bus capacities, etc.). Though algorithms have produced between 10-30% cost and time savings, computer-aided routing systems are not widely accepted because of the oversimplification of assumptions that sometimes occur (Chen et al., 1988). It is thus important to separate the knowledge from the algorithm that uses that knowledge so as to allow the user to participate in the solution process.

2.3.1 VersaTrans

Though DPS was not involved in the development process of VersaTrans RP, the routing and scheduling software currently in place to assist the school, it was provided with the necessary training to effectively use the software. VersaTrans has a long history with routing and scheduling school buses, and the program offered has been used by DPS for over a decade. VersaTrans RP, currently in its ninth edition, is claimed to be “the world’s most flexible and easiest-to-use school bus routing and planning solution for people who develop school bus schedules, map out routes, plan district boundaries and respond to ongoing changes in schedules and student population” (32). It is also SIF-certified for the Schools Interoperability Framework, which helps schools improve the sharing of information and streamlining of decision making.

VersaTrans RP has been in existence for over 20 years. The company has successfully included the transportation community in their software development process in order to fulfill their specific needs. The company offers a plethora of services:

- A complete, low-impact implementation service that provides clients with a detailed transportation orientated map that goes through two client-review phases. The map, which is tailored specifically for each district, includes district bus stops, district/school boundaries, walk boundaries, hazard zones, hazardous streets, cross-street restrictions, right-side only pickups, and school locations.
- Professional software installation
- Thorough Training from specialists who ensure that district planers and routers have a clear understanding of the software features used the most.
- A 24/7 online/toll-free service that provides clients with rapid, thorough, unlimited technical support.

2.4 Conclusions

The Literature for vehicle routing and scheduling classifies practical problems in various ways. Due to the difficulty of the problem, most of the approaches found use heuristics to find approximate solutions. In the case of the cost assessment of DPS' operating procedures, the VersaTrans routing and scheduling software is utilized. Due to its proprietary nature, the specific algorithm or method used by the software is not known. However, it is known that that it is heuristic in nature as VersaTrans readily admits that once routes are built, routers can generally find marginally more efficient routes by tinkering with them.

The next chapter is organized as a stand-alone article to be used as a possible submission to an academic journal.

III. JOURNAL ARTICLE

3.1 INTRODUCTION

Minimizing the costs associated with school bus routing is a common problem faced by logistical planners in today's resource constrained world. In fact, over a hundred firms offer proprietary software to aid school districts in that exact endeavor. With rising fuel costs and a deep economic recession looming, school districts across the nation are, more than ever, being forced to find ways to cut costs in their operations, while continuing to provide children with the quality education they will need to compete in an increasingly global market. One of the more obvious potential sources for savings can be found in transportation, specifically with routing and scheduling.

The Dayton Public Schools (DPS) Transportation Community Collaborative was formed to provide an unbiased group to help DPS streamline its transportation operation. Its members include a wide range of individuals from the community: the DPS associate superintendant, the director of DPS transportation, city of Dayton planning, community development and fleet management representatives, principals, teachers, bus drivers and union affiliates, Greater Dayton Regional Transit Authority colleagues, OAPSE regional representatives, SVA contractors, business leaders, operation research professors, and parents. The ultimate responsibility of this group is to ensure safe and efficient transportation is provided to as many of its city pupils as possible, while trimming some of the fat from its transportation operation. The biggest limitation to efficient routing comes from the importance DPS places on customer satisfaction. In order to provide quality customer service, however, the ability to maintain efficient routes has become a

distant thought. In an effort to get back to the basics of its operations, DPS decision makers have come together to unearth efficiency improvement opportunities that may exist within its enterprise.

The main thrust of this paper is to investigate the routing and scheduling of DPS yellow school buses for regular-education kindergarten thru eighth grade students. Specifically, we seek to examine the potential savings that may be available through streamlining and/or consolidating bus routes. DPS policy states that, excluding extenuating circumstances, it will not provide transportation to students within a two mile radius of their intended school, nor will it alter bus schedules and routes to meet individual family circumstances. Nevertheless, exceptions are so commonplace that DPS has essentially been reduced to, as the industry describes, “curb-to-curb” pickup and deliveries. This means that DPS is adding bus stops in such a fashion, that Dayton pupils are being served at their doorsteps.

The primary intention of this research is to illustrate the savings that may be revealed by instituting neighborhood or “straight line” bus stops. Straight line stops are those placed on main roads that have been designated safe by DPS officials. As discussed by Bodin et al. (1983), a source of considerable savings will come from parting with the door-to-door student pickup methodology and establishing centralized “ministops” to which students must walk. Once in place, we will use the VersaTrans optimization/heuristic software to route students by way of these stops. VersaTrans serves as the primary optimization software used to develop routes in an attempt to change the way DPS conducts business. Once routes are constructed, an optimal bell schedule is developed to minimize the number of buses required. In this way, a process

for building cost effective routes can be instituted which is transparent and repeatable. The biggest hurdle in dealing with DPS consists of ensuring that the savings recouped in implementing the new transportation methodology justifies the decrease in customer satisfaction.

3.2 PERTINENT LITERATURE

3.2.1 The Scheduling Problem

Scheduling is a managerial process that is instrumental in many transportation and distribution settings. Typically, the schedule adopted by an organization will have major impacts on the organization's performance. Scheduling is defined as allocating scarce resources to tasks over time (Pinedo, 2005). In the case of school buses, it specifically deals with assigning particular buses to routes.

Ample attention has been given to school bus scheduling in the past. Angel et al. (1979), Bodin and Berman (1979), Chen et al. (1988), and Swersey and Ballard (1984) have all developed approaches to determine bus schedules. School bus scheduling is regarded as more important than the Vehicle Routing Problem (VRP) when considering their effective utilization in an urban setting (Bodin, 2001). The reason behind this is that a single bus in a fleet can run many routes in a day. Thus, effective scheduling will greatly reduce the number of buses needed by the district. Once the routing component is complete, the student loads on each of the routes are no longer constraints in the scheduling component. The problem of simultaneously solving the school bus routing and scheduling problem can now, therefore, be avoided because we need only construct a minimum number of routes and then expertly schedule buses to them. If one is permitted to change the starting and ending times of the schools in a school district to

reduce the number of students traveling during peak times, then an overall reduction in the number of buses needed can be realized (Bodin, 2001).

3.2.2 The Vehicle Routing Problem

The Vehicle Routing Problem (VRP) is a complex combinatorial optimization problem that has challenged operational researchers for more than 40 years. Introduced by Danzig and Ramser in 1959, this NP-Hard problem can be described by combining two well known problems: the Traveling Salesman Problem (TSP) and the Bin Packing Problem (BPP) (Ralphs, 2003). The VRP has a plethora of real world applications, which has sparked much interest over the past several decades. Angel et al. (1979), Bodin and Berman (1979), Chen et al. (1988), Cordeau (2006), Ralphs (2003), and Repoussis (2007) have each approached routing in various ways.

The Capacitated Vehicle Routing Problem (CVRP) is the most general version of the VRP (Machado, 2002). It can be formulated by designing an optimal set of minimum cost routes for a fleet of k independent, homogeneous vehicles originating at a common depot, 0 , and servicing the demands, d_i , of n customers (schools/students). The routes must be designed such that each point is visited only once by exactly one vehicle, all routes start and end at the depot, and the total demands of all points on one particular route cannot exceed the capacity of the vehicle. The cost is determined by c_{ij} , the distance from customer i to customer j . The distance between customers is symmetric, i.e. $c_{ij} = c_{ji}$, and $c_{ii} = 0$. A graphical representation is presented in Figure 1, where the nodes represent customers and arcs represent routes.

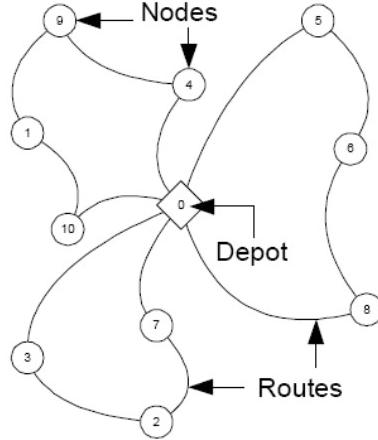


Figure 1: Vehicle Routing Problem

In application, the size of the problem instance generally becomes much too large to solve with typical integer programming methods. Most approaches for the VRP rely on heuristics to generate near optimal solutions in a reasonable amount of time (Machado, 2002). To accurately apply the practical application of the VRP to school bus routing, it must be manipulated in various ways. Bodin et al (1979, 1983) provides a detailed depiction of the many nuances that are associated with this problem.

In order to construct a set of minimum cost routes for the district's fleet, we can define our objective as minimizing the fleet's operating cost and the number of vehicles used. Since there has not been much research conducted in the combined routing and scheduling problem, it is customary to break it down into three parts: selecting the starting and ending times of the schools, building partial vehicle routes, and forming daily bus schedules (Bodin, 1983). It is generally assumed in much of the literature that we will have a homogenous fleet with identical capacities which carry identical goods. As we change these assumptions, our problem instance becomes much more intractable as we introduce several additional variables and constraints to the formulation. The

literature for vehicle routing and scheduling classifies practical problems in various ways. Due to the difficulty of the problem, most of the approaches found use heuristics to find approximate solutions.

3.3 METHODOLOGY

3.3.1 Routing Automation

The purpose of an automated school bus routing and scheduling system is not only to minimize the transportation costs incurred by the school district in question, but also to minimize the average transportation time of each student and, most importantly, provide an automated procedure for setting up daily schedules for the fleet (Bodin, 1979). There are several methods available to analysts and institutions to create routing programs. If one conducts a simple Google search for school bus routing, hundreds of sites are found advertising proprietary software. InterGis, Fleet Matics, VersaTrans, Express Technologies, and Orbit Software are just a few of the more prominent businesses offering their services.

One must be careful, however, about the ad hoc purchase and implementation of packages picked off the shelf. Many of these systems either do not involve the user or veteran route designer in the solution process, or do not provide the necessary knowledge behind the algorithms involved (Chen et al., 1988). Additionally, many of these algorithms do not account for non-quantifiable factors such as safety, preference, and judgment. Assumptions may, for example, be fuzzy and not uniform, constraints may be soft as opposed to rigid, and the objectives may be to simply satisfy, rather than optimize, certain criteria (Chen et al., 1988). Therefore, it is important to pick software that has been developed with an expert system approach by which the problem environment (i.e.

road maps, school locations, bus capacities, etc.) is kept separate from the solution execution.

3.3.2 Software Utilization

DPS transportation currently uses the software package VersaTrans RP to partially automate its routing and scheduling of its school buses throughout the district. Though DPS was not involved in the development process of VersaTrans RP, it was provided with the necessary training to effectively use the software. VersaTrans has a long history with routing and scheduling school buses, and the program offered has been used by DPS for over a decade. VersaTrans RP, currently in its ninth edition, claims to be “the world’s most flexible and easiest-to-use school bus routing and planning solution for people who develop school bus schedules, map out routes, plan district boundaries and respond to ongoing changes in schedules and student population” (32). It has been in existence for over 20 years, and the company has successfully included the transportation community in their software development process in order to fulfill their specific needs.

It is only natural to conduct our cost assessment using a software package that has not only been verified, validated, and accredited by the transportation community, but is also readily available and understood by DPS routing staff. For that reason, VersaTrans serves as the primary optimization software used to develop more efficient routes. Due to its proprietary nature, we do not know the specific algorithm or method used by the software. We do know, however, that it is heuristic in nature, as VersaTrans readily admits that once routes are built, routers can generally find marginally more efficient routes by tinkering with them.

3.3.2 Data Organization

The input required for the routing problem include a list of available bus stops, the nodes representing the schools and central depot, the number of students assigned to each bus stop, and the travel time between each pair of bus stops. Most procedures for routing buses are adaptations of either the “route first-cluster second” procedure for routing or the “cluster first-route second” technique, which is described by Bodin et al. (1983) in great detail. Angel et al. (1972) stress that the data collection and preparation phase requires complete student census information with regard to the location and number of students and bus stops.

As with many types of analysis, the most time-consuming and tedious aspect of routing and scheduling of school buses involves the input data. Dealing with bus stops in school districts tends to take the most effort in the data management process. DPS currently serves three types of stops: regular education, special needs, and curb-to-curb. For the purposes of this paper, we deal with only the regular education bus stops.

3.3.3 DPS Routing Scenarios

Many scheduling techniques exist that school districts can exploit in their cost saving endeavors. In most instances, data must first be fed in from the routing phase. This paper examines three possibilities to generate savings: a required walking distance for children that live less than 1.5 miles from their school and are not subject to hazardous conditions, optimally placed neighborhood stops, and a combination of a more stringent 2 mile walking requirement with neighborhood stops.

DPS currently has a policy that children will not be offered transportation if they live within 2 miles of their school of choice. To keep in line with offering outstanding

customer satisfaction, exceptions to this policy are often made for various reasons. By examining a conservative 1.5 mile walking requirement scenario for students that live within that distance of their respective school, potential savings can be gleamed. To accomplish this, it is necessary to create “walking boundaries” that extend around each school. As seen in Figure 2, roads that are bolded represents the 1.5 mile boundary that surrounds a particular school, in this case Emerson, and the solid line corresponds to the “walking boundary.” VersaTrans recognizes this boundary, and during the bus stop assignment process, the program will assign children that fall within the boundary as walkers.

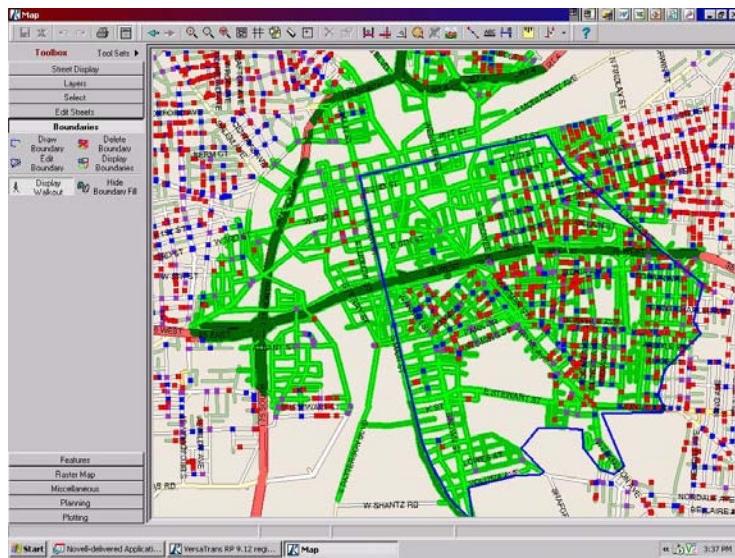


Figure 2: Walking Boundaries

The small solid squares in Figure 2 represent the bus stops within the district. Each stop is color coded to indicate which of the three types of bus stops DPS services. A cursory look at the regular education bus stops indicates that there are many more stops available than are necessary. One reason for this is that, when a child moves to a new location or out of the district completely, the original bus stop is never removed. Over

the course of one or more school years, the data containing the list of bus stops becomes cluttered and unwieldy. Additionally, VersaTrans' procedure for assigning children to stops is not intended to place students at optimally located stops. Hence, to better manage the district stops and minimize the amount of input data required, Bodin (2001) introduces a “ministop” concept. These are locations in the district which can be used as distinct bus stops for groups of children. The DPS community refers to this notion as a neighborhood or “straight line” bus stop. However, straight line stops have an additional requirement to be placed on main or major roads. Straight line bus stops have given rise to concern because “main” roads may be overly congested and dangerous for younger children. Hence, it is more realistic to place bus stops on secondary roads which have less traffic. Due to this requirement, we can rely less on placing stops that are centrally located among the largest number of children and rely more on the expert knowledge of the routers.

This leads us to our second scenario, the neighborhood stop concept. DPS routers are consulted to determine which roads are best positioned to serve as our neighborhood stops. Regular education bus stops are then reassigned. Stops that we wish to designate as inactive are marked “null,” whereby stops remain active or are created as “DPS” if we want to allow VersaTrans to assign students to them. The stops are placed such that they are located further than 0.2 miles from each other along these “safe” roads.

Each student in the district is assigned to the neighborhood stop closest to his home. This is important because the neighborhood stop a student belongs to remains unchanged, regardless of whether the student attends elementary school, junior high, or high school, as long as he does not move. While assigning children to these

neighborhood stops, we remain cognizant of the fact that DPS follows a policy by which a student cannot walk more than half a mile from his place of residence to a bus stop.

Our final scenario simply combines these two methodologies, while increasing our school walking boundaries to 2 miles to stay in line with stated DPS policy. These three problem settings should give DPS the necessary data to make an informed decision.

3.3.4 DPS Route Construction

Once students have been assigned as riders or walkers, and the riders have been appointed to their bus stops by VersaTrans, we will use the VersaTrans optimization/heuristic software to route the riders by way of these stops. As seen in Figure 3, there are several routing parameters that can be used by the VersaTrans routing heuristic, entitled One Touch Routing (OTR).

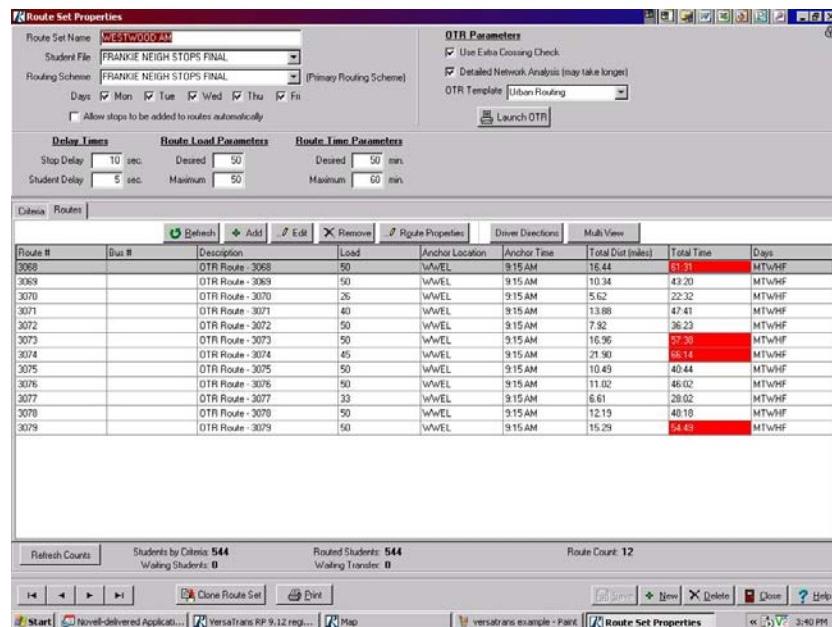


Figure 3: DPS Route Construction Example

In order to compare apples to apples, we will leave the delay times and route load parameters the same. As seen by Angel et al. (1972), VersaTrans uses constant loading

times and driving speeds in its algorithm. If buses are required to stop more often (i.e. in an urban setting such as seen at DPS), then starting and stopping times become important because travel times are generally not related to the number of bus stops (Angel et al., 1972; Swersey and Ballard, 1984). These parameters have been considerably scrutinized by the DPS staff.

Once routes are constructed, the VersaTrans Fleet optimization software can create a bell schedule which will best utilize the routes created in order to minimize the number of buses required. In this way, a process for building cost effective routes can be instituted which is transparent and repeatable.

3.4 DPS SPECIFIC PROBLEM ENVIRONMENT

DPS currently operates one-hundred and ninety-seven buses and travels twenty-three thousand miles a day. Operating costs exceed thirteen million dollars annually. Surprisingly, fuel represents just 15% of those expenditures, at two million dollars. DPS serves approximately twenty-six thousand students daily, twelve thousand of which require public transportation. The capacity of each bus averages sixty-six passengers for elementary students and forty-four passengers for middle and high school students. The difference in capacity is associated with the different sizes of the students. Hence, the buses can not necessarily be looked at as a homogeneous fleet unless the problem is partitioned by student type. DPS currently follows a four-tiered bell schedule for its kindergarten thru eighth grade students for the 2008 thru 2009 school year (see Table 1).

Table 1: PK – 8, Elementary and Middle Schools

7:15 AM – 1:45 PM	
Gardendale (Grades K-12)	Stivers (Grades 7 - 8) Wilbur Wright
7:45 AM – 2:00 PM	
Belle Haven	Longfellow (Grades 1 – 8)
Eastmont	Meadowdale Elem.
Edison	Ruskin
Franklin Montessori	World of Wonder
8:35 AM – 2:50 PM	
Louise Troy	Rosa Parks
Cleveland	EJ Brown
Horace Mann	Wogaman
9:25 AM – 3:40 PM	
Charity Adams Earley	Kiser
Dayton Boys Prep Academy	Loos
Fairview Elem.	Orville Wright
Gorman	Patterson Kennedy
Westwood	Preschool Academy at Jackson Center
Kemp @ Grant	Valerie

In addition to its 29 schools, it also must service 32 non parochial and charter schools (see appendix A).

These initial conditions provide us with our baseline scenario for which to test against. They represent DPS' state of affairs as of January 15, 2009 and are shown in Table 2 below.

Table 2: Current DPS Route Statistics

Study	Routes	Avg Riders Per Bus	Total Route Mileage	Average Route Mileage	Average Route Time
Current DPS AM Routes	372	35	7424.34	19.96	62
Current DPS PM Routes	367	36	7496.20	20.43	63

The statistics show that DPS currently places approximately 2 students at each regular education stop and have 35 students per bus. With an average capacity of 50 for each bus, DPS' capacity utilization is at 65.45%, which is slightly below the 70% minimum to be classified as a "well run school," according to a document produced by the Dayton Transportation Collaborative. With an average route time of 62 minutes, DPS is presently in line with its target time utilization of 60 minutes.

Table 3 illustrates DPS' current bus statistics. DPS states that children in grades k thru 8 have a 1:1 ratio to seats, whereas children in grades 7 thru 8 have a 1.5:1 ratio. The student data, therefore, suggests that we can assume that the average capacity of a 65 passenger bus is 50 students.

Table 3: Current DPS Bus Statistics

Study	Buses Used	Buses Over Capacity
Current DPS AM Buses	169	62
Current DPS PM Buses	179	61

DPS therefore utilizes approximately 179 buses per day. Note that the PM routes constrain the routing environment. This is contrary to what is perused in the literature. It is also noteworthy to mention that DPS has several buses that are over capacity. Therefore, it is safe to assume that we can apply a rule that on any given day, there will

be a percentage of students who will be “no-shows”, as is commonly practiced in the airline industry.

3.5 RESULTS AND ANALYSIS

The results presented are for the three scenarios previously mentioned: a 1.5 mile boundary with default stops, neighborhood stops with default walking boundaries, and a combined 2 mile walking boundary with neighborhood stops. The intention of this study is to reduce the number of routes driven, buses used, and mileage traveled, while simultaneously meeting route time and bus capacity milestones. The most valuable information to the client as it relates to routes appears in Table 4. These figures show the different statistics associated with executing each of the three scenarios.

All three scenarios show improvement over the current routes. The worst performing scenarios occur in the neighborhood stop and 1.5 Mile Boundary PM routes. In these scenarios, the number of routes and total route mileage traveled are reduced by 15.60% and 10.34%, respectively, while the number of riders per bus is increased by 13.89%. Our best overall scenario is the 2 mile neighborhood stop study. This is expected because we are increasing the required walking distance and combining the neighborhood stops concept, each of which individually resulted in savings. We evaluate this scenario as a mini-max problem. The AM or PM partition with the larger amount of required route/miles traveled will serve as the driving force behind the scheduling component. Here, the number of routes and total route mileage traveled is reduced by 31.20% and 48.51%, respectively, while the number of riders per bus is increased by 13.88% from our baseline case.

Table 4: Route Results

Study	Routes	Avg Riders Per Bus	Total Route Mileage	Average Route Mileage	Average Route Time
Current DPS AM Routes	372	35	7424.34	19.96	62.00
Current DPS PM Routes	367	36	7496.20	20.43	63.00
Neighborhood Stop AM Routes	303	42	4419.31	14.59	50.31
Neighborhood Stop PM Routes	314	41	4382.12	13.96	48.58
1.5 Mile Boundary AM Routes	311	39	6709.79	21.57	64.54
1.5 Mile Boundary PM Routes	305	41	6721.13	23.00	66.15
2 Mile/Neighborhood AM Routes	256	41	3859.78	15.08	50.77
2 Mile/Neighborhood PM Routes	272	40	4095.34	15.06	50.30

The results show that, without even considering the scheduling problem, considerable improvements in transportation operations can be realized. The reduced mileage alone will undoubtedly result in reduced operation and maintenance costs. Additionally, DPS will significantly reduce its greenhouse gas contribution to the Dayton, Ohio environment. As the world begins to become much more environmentally conscious, a ten to forty percent drop in pollution output by operating slightly differently and more in line with policy will set a clear example to the rest of the community. Finally, with a two million dollar yearly expenditure for fuel, the reduction will free up between \$200,000 and \$800,000.

4.2 Bell Schedule Results

VersaTrans is also used to construct a bell schedule for each of the scenarios previously mentioned. Unfortunately, the scheduling software is limited in its capability. VersaTrans needs initial anchor times for which to assign buses to routes. Hence, the

analyst must have an idea as to what type of bell schedule he wishes to institute. Given the fact that the number of routes serviced in each of the scenarios were drastically reduced, it is assumed that using VersaTrans to schedule buses would provide added savings above Operation, Maintenance, and fuel costs. A three and four tiered bell schedule based on the number of buses used by each school is therefore constructed with the aid of experienced DPS routers. The two bell schedules created are displayed in Tables 5 and 6.

Table 5: 3 Tier Bell Schedule

730 - 145		830 - 245		930-345	
School	Routes	School	Routes	School	Routes
BELLE HAVEN PM	12	CITY DAY PM	5	C ADDAMS PM	9
HOLY ANGELS PM	5	CLEVELAND PM	10	D ACADEMY PM	13
EASTMONT PM	14	E J BROWN PM	11	D VIEW PM	13
EDISON PM	10	LOOS PM	8	FAIRVIEW ES PM	9
FRANKLIN PM	8	LOUISE TROY PM	10	N DAYTON PM	10
M Q PEACE I PM	4	O L ROSARY PM	3	NEW KEMP PM	9
NEW CITY	3	PATHWAY PM	6	O WRIGHT PM	8
MEADOWDALE PM	12	PRECIOUS BLD PM	4	H MANN PM	11
W WRIGHT PM	13	RICH ALLEN PM	11	P KENNEDY PM	14
ACADEMY OF DAYTC	4	ROSA PARKS PM	10	ASCENSION PM	2
WOW PM	10	ST RITA PM	6	VALERIE PM	9
LONGFELLOW OK-08	3	NCHOICE PM	4	WESTWOOD PM	15
TROTWOOD FIT PM	5	SUMMIT ACD PM	1		
NU BETHEL	2	IMAGINE PM	2		
STIVERS PM	9	WOGAMAN PM	10		
E DAY CHRIST PM	2	EMERSON PM	10		
ST HELEN PM	2	RUSKIN PM	4		
IMC	1	KISER PM	9		
Total	126	Total	124	Total	122

Table 6: 4 Tier Bell Schedule

School	Routes	School	Routes	School	Routes	School	Routes
BELLE HAVEN PM	12	CLEVELAND PM	10	CITY DAY PM	5	PRECIOUS BLD PM	4
TROTWOOD FIT PM	5	E DAY CHRIST PM	2	IMAGINE PM	2	D ACADEMY PM	13
NU BETHEL	2	E J BROWN PM	11	LOOS PM	8	D VIEW PM	13
LONGFELLOW OK-08 PM	3	EMERSON PM	10	LOUISE TROY PM	10	FAIRVIEW ES PM	9
MEADOWDALE PM	12	C ADDAMS PM	9	N DAYTON PM	10	KISER PM	9
STIVERS PM	9	E DAY CHRIST PM	2	ASCENSION PM	2	NEW KEMP PM	9
W WRIGHT PM	13	ST HELEN PM	2	O WRIGHT PM	8	H MANN PM	11
ACADEMY OF DAYTON PM	4	IMC	1	O L ROSARY PM	3	P KENNEDY PM	14
WOW PM	10	ROSA PARKS PM	10	PATHWAY PM	6	WESTWOOD PM	15
FRANKLIN PM	8	SUMMIT ACD PM	1	RICH ALLEN PM	11		
EASTMONT PM	14	NCHOICE PM	4	ST RITA PM	6		
HOLY ANGELS PM	5	RUSKIN PM	4	TROTWOOD FIT P	5		
		ST HELEN PM	2	VALERIE PM	9		
		New City	3	EDISON PM	10		
		M Q PEACE I PM	4				
		HORIZON PM	7				
		WOGAMAN PM	10				
Total	97		92		95		97

Again, there were several routes in the original routing method that use a mixed pallet methodology. Since it was desired to keep the routing schemes for our analysis as close as possible to the original routes, we followed this design. Hence, we must be cognizant of the fact that these schools need to be in the same tier. Great effort was used to keep schools in their original tier, or as close to it as possible. The bolded schools are those that have routes that are mixed.

Currently, many of the charter and non public schools do not follow the six hour and fifteen minute school day. However, for our study, we aligned all schools into this timetable. If major savings are found, it can be argued that a consolidated bell schedule makes sense and is worth considering. DPS is currently on a modified schedule, placing middle schools in the first tier and k – 8 schools in the remaining three.

These bell schedules were tested on our three scenarios. The results obtained by using the new bell schedule anchor times are presented in Table 7 and 8. The percentage

change is compared against the corresponding DPS AM routes of 169 buses or PM routes of 179. A 3 tiered bell schedule results in savings over the current method in place.

Table 7: 3 Tier Bell Schedule Results

Study	Buses Used	% Change
Current DPS AM Buses	169	0.00%
Current DPS PM Buses	179	0.00%
Neighborhood Stop AM Routes	144	-14.79%
Neighborhood Stop PM Routes	148	-17.32%
1.5 Mile Boundary AM Routes	143	-15.38%
1.5 Mile Boundary PM Routes	147	-17.88%
2 Mile/Neighborhood AM Routes	127	-24.85%
2 Mile/Neighborhood PM Routes	147	-17.88%

Note that though we have buses that are over capacity, none of the scenarios surpass DPS' current operating procedures of running with 62 buses over capacity. Over capacity is defined as any bus carrying more than 50 children.

The 4 tiered bell schedule outperforms the 3 tiered schedule in the neighborhood stops and 2 mile/Neighborhood scenarios. VersaTrans is able to reduce the number of buses used in the neighborhood stop scenario by one bus and in the 2 mile/neighborhood scenario by 12. It uses 2 additional buses in the 1.5 mile boundary scenario. This produces 12 to 23% savings when compared to our baseline case. Hence, VersaTrans algorithm for assigning buses performs very well.

Table 8: 4 Tier Bell Schedule Results

Study	Buses Used	% Change
Current DPS AM Buses	169	0.00%
Current DPS PM Buses	179	0.00%
Neighborhood Stop AM Routes	147	-13.02%
Neighborhood Stop PM Routes	145	-18.99%
1.5 Mile Boundary AM Routes	148	-12.43%
1.5 Mile Boundary PM Routes	149	-16.76%
2 Mile/Neighborhood AM Routes	130	-23.08%
2 Mile/Neighborhood PM Routes	135	-24.58%

Given that each bus costs approximately \$140,000 per year on average to operate, this equates to savings of between 4.4 and 6 million dollars a year.

3.6 CONCLUSIONS

This paper has demonstrated that significant savings can be found by using available, off the shelf routing software to construct routes and schedule buses to them. In the case of the Dayton Public School district, VersaTrans is more than capable of handling its everyday needs. Major factors that impact routing efficiency are school walking distance requirements and the placement of bus stops. Scheduling is mainly affected by the number of routes required and the bell schedule chosen. Implementing more stringent requirements in any of these areas will generally result in savings. However, changing them in conjunction, by requiring students to walk to school if they live within 2 miles of the school, while placing neighborhood stops that are at least 0.2

miles apart from each other, results in the largest amount of savings when considering routes served, miles traveled, and buses used.

As aforementioned, the environment at DPS has changed since the initiation of this study. Nonetheless, the boundaries and neighborhood stops are available for DPS' use within VersaTrans. Due to VersaTrans automation capabilities, DPS now has the tools necessary to execute any of the scenarios presented in this paper.

IV. Results and Conclusions

4.1 Introduction

VersaTrans was used to analyze three scenarios involving neighborhood stops and mandatory walking boundaries for students that live within and attend the school contained within that boundary. Once the routes for these scenarios were constructed, bell schedules were produced to minimize the number of school buses needed to serve DPS' students.

4.2 Route Results

The results presented are for the three scenarios previously mentioned: a 1.5 mile boundary with default stops, neighborhood stops with default walking boundaries, and a combined 2 mile walking boundary with neighborhood stops. The intention of this study is to reduce the number of routes driven, buses used, and mileage traveled, while simultaneously meeting route time and bus capacity milestones. The most valuable information to the client as it relates to routes appears in Table 4. These figures show the different statistics associated with running each of the three scenarios.

All three scenarios show improvement over the current routes. The worst performing scenarios occur in the neighborhood stop and 1.5 Mile Boundary PM routes. In these scenarios, the number of routes and total route mileage traveled are reduced by 15.60% and 10.34%, respectively, while the number of riders per bus is increased by 13.89%. Our best overall scenario is the 2 mile neighborhood stop study. We evaluate this scenario as a mini-max problem. The AM or PM partition with the larger amount of required route/miles traveled will serve as the driving force behind the scheduling

component. Here, the number of routes and total route mileage traveled is reduced by 31.20% and 48.51%, respectively, while the number of riders per bus is increased by 13.88% from our baseline case.

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2 Mile/Neighborhood AM Routes	256	41	3859.78	15.08	50.77
2 Mile/Neighborhood PM Routes	272	40	4095.34	15.06	50.30

The results show that, without even considering the scheduling problem, considerable improvements in transportation operations can be realized. The reduced mileage alone will undoubtedly result in reduced operation and maintenance costs. Additionally, DPS will significantly reduce its greenhouse gas contribution to the Dayton, Ohio environment. As the world begins to become much more environmentally conscious, a ten to forty percent drop in pollution output by operating slightly differently and more in line with policy will set a clear example to the rest of the community. Finally, with a two million dollar yearly expenditure for fuel, the reduction will free up between \$200,000 and \$800,000.

4.3 Bell Schedule Results

VersaTrans is also used to construct a bell schedule for each of the scenarios previously mentioned. Unfortunately, the scheduling software is limited in its capability. VersaTrans needs initial anchor times for which to assign buses to routes. Hence, the analyst must have an idea as to what type of bell schedule he wishes to institute. The results obtained by using the original bell schedule anchor times are presented in Table 5. The percentage change is compared against the corresponding DPS AM routes of 169 buses or PM routes of 179 buses. Using the maximum number of buses needed from the AM or PM portion, we generate savings of between 2 and 10%. Note that though we have buses that are over capacity, none of the scenarios surpass DPS' current operating procedures of running with 62 buses over capacity. Over capacity is defined as any bus carrying more than 50 children.

Table 5: Initial Bus Results

Study	Buses Used	% Change	Buses Over Capacity
Current DPS AM Buses	169	0.00%	62
Current DPS PM Buses	179	5.92%	61
Neighborhood Stop AM Routes	165	-2.37%	57
Neighborhood Stop PM Routes	150	-16.20%	51
1.5 Mile Boundary AM Routes	164	-2.96%	33
1.5 Mile Boundary PM Routes	147	-17.88%	51
2 Mile/Neighborhood AM Routes	152	-10.06%	43
2 Mile/Neighborhood PM Routes	151	-15.64%	28

Given the fact that the amount of routes serviced in each of the scenarios were drastically reduced, it is assumed that by using the bus assignments currently in place at DPS would provide more savings. As seen in Table 6, this procedure generates additional savings of between 13 and 20%, depending on the scenario of interest. Given that each bus costs approximately \$140,000 per year on average to operate, this equates to savings of between 4.4 and 6 million dollars a year.

Table 6: DPS Bus Assignment Results

Study	Buses Used	% Change
Current DPS AM Buses	169	0.00%
Current DPS PM Buses	179	0.00%
Neighborhood Stop AM Routes	147	-13.02%
Neighborhood Stop PM Routes	145	-18.99%
1.5 Mile Boundary AM Routes	146	-13.61%
1.5 Mile Boundary PM Routes	141	-21.23%
2 Mile/Neighborhood AM Routes	136	-19.53%
2 Mile/Neighborhood PM Routes	135	-24.58%

A final assessment was conducted by designing a three and four tiered bell schedule based on the number of buses used by each school. These bell schedules were created with the aid of DPS' experienced routers. Again, there were several routes in the original routing method that use a mixed pallet methodology. Since it was desired to keep the routing schemes for our analysis as close as possible to the original routes, we followed this design. Hence, we must be cognizant of the fact that these schools need to be in the same tier. Great effort was used to keep schools in their original tier, or as close

to it as possible. Currently, many of the charter and non public schools do not follow the six hour and fifteen minute school day. However, for our study, we aligned all schools into this schedule. If major savings are found, it will not be difficult to argue that a consolidated bell schedule makes sense and is worth considering. The two bell schedules created are displayed in Tables 7 and 8. The bolded schools are those that have routes that are mixed. DPS is currently on a modified schedule, placing middle schools in the first tier and k – 8 schools in the remaining three.

Table 7: 3 Tier Bell Schedule

730 - 145		830 - 245		930-345	
School	Routes	School	Routes	School	Routes
BELLE HAVEN PM	12	CITY DAY PM	5	C ADDAMS PM	9
HOLY ANGELS PM	5	CLEVELAND PM	10	D ACADEMY PM	13
EASTMONT PM	14	E J BROWN PM	11	D VIEW PM	13
EDISON PM	10	LOOS PM	8	FAIRVIEW ES PM	9
FRANKLIN PM	8	LOUISE TROY PM	10	N DAYTON PM	10
M Q PEACE I PM	4	O L ROSARY PM	3	NEW KEMP PM	9
NEW CITY	3	PATHWAY PM	6	O WRIGHT PM	8
MEADOWDALE PM	12	PRECIOUS BLD PM	4	H MANN PM	11
W WRIGHT PM	13	RICH ALLEN PM	11	P KENNEDY PM	14
ACADEMY OF DAYTC	4	ROSA PARKS PM	10	ASCENSION PM	2
WOW PM	10	ST RITA PM	6	VALERIE PM	9
LONGFELLOW OK-08	3	NCHOICE PM	4	WESTWOOD PM	15
TROTWOOD FIT PM	5	SUMMIT ACD PM	1		
NU BETHEL	2	IMAGINE PM	2		
STIVERS PM	9	WOGAMAN PM	10		
E DAY CHRIST PM	2	EMERSON PM	10		
ST HELEN PM	2	RUSKIN PM	4		
IMC	1	KISER PM	9		
Total	126	Total	124	Total	122

Table 8: 4 Tier Bell Schedule

School	Routes	School	Routes	School	Routes	School	Routes
BELLE HAVEN PM	12	CLEVELAND PM	10	CITY DAY PM	5	PRECIOUS BLD PM	4
TROTWOOD FIT PM	5	E DAY CHRIST PM	2	IMAGINE PM	2	D ACADEMY PM	13
NU BETHEL	2	E J BROWN PM	11	LOOS PM	8	D VIEW PM	13
LONGFELLOW OK-08 PM	3	EMERSON PM	10	LOUISE TROY PM	10	FAIRVIEW ES PM	9
MEADOWDALE PM	12	C ADDAMS PM	9	N DAYTON PM	10	KISER PM	9
STIVERS PM	9	E DAY CHRIST PM	2	ASCENSION PM	2	NEW KEMP PM	9
W WRIGHT PM	13	ST HELEN PM	2	O WRIGHT PM	8	H MANN PM	11
ACADEMY OF DAYTON PM	4	IMC	1	O L ROSARY PM	3	P KENNEDY PM	14
WOW PM	10	ROSA PARKS PM	10	PATHWAY PM	6	WESTWOOD PM	15
FRANKLIN PM	8	SUMMIT ACD PM	1	RICH ALLEN PM	11		
EASTMONT PM	14	NCHOICE PM	4	ST RITA PM	6		
HOLY ANGELS PM	5	RUSKIN PM	4	TROTWOOD FIT P	5		
		ST HELEN PM	2	VALERIE PM	9		
		New City	3	EDISON PM	10		
		M Q PEACE I PM	4				
		HORIZON PM	7				
		WOGAMAN PM	10				
Total	97		92		95		97

These bell schedules were tested on our three scenarios. The results are illustrated in Tables 9 and 10. Using a 3 tiered bell schedule results in savings over the current method in place; however, it does not perform better than using our simplified approach of using the current bus DPS assignments. This is not surprising considering that in a 3 tiered schedule each tier will require more buses. With this configuration, it is more difficult to operate buses in multiple tiers. Nonetheless, for an automated process, it performs fairly well.

Table 9: 3 Tier Bell Schedule Results

Study	Buses Used	% Change
Current DPS AM Buses	169	0.00%
Current DPS PM Buses	179	0.00%
Neighborhood Stop AM Routes	144	-14.79%
Neighborhood Stop PM Routes	148	-17.32%
1.5 Mile Boundary AM Routes	143	-15.38%
1.5 Mile Boundary PM Routes	147	-17.88%
2 Mile/Neighborhood AM Routes	127	-24.85%
2 Mile/Neighborhood PM Routes	147	-17.88%

The 4 tiered bell schedule, on the other hand, does perform just as well as our simplified approach. The results in the neighborhood study are identical, and it reduces the 2 mile boundary with neighborhood stops bus usage by one. It does struggle in the 1.5 mile boundary with default stops, using 2 additional buses. This produces 12 to 23% savings when compared to our baseline case. Hence, VersaTrans algorithm for assigning buses performs as well as constructing them by hand.

Table 10: 4 Tier Bell Schedule Results

Study	Buses Used	% Change
Current DPS AM Buses	169	0.00%
Current DPS PM Buses	179	0.00%
Neighborhood Stop AM Routes	147	-13.02%
Neighborhood Stop PM Routes	145	-18.99%
1.5 Mile Boundary AM Routes	148	-12.43%
1.5 Mile Boundary PM Routes	149	-16.76%
2 Mile/Neighborhood AM Routes	130	-23.08%
2 Mile/Neighborhood PM Routes	135	-24.58%

4.4 Conclusions

This research has demonstrated that significant savings can be found by using available, off the shelf routing software to construct routes and schedule buses to them. In the case of the Dayton Public School district, VersaTrans is more than capable of handling its everyday needs. Major factors that impact routing efficiency are school walking distance requirements and the placement of bus stops. Scheduling is mainly affected by the number of routes required and the bell schedule chosen. Implementing more stringent requirements in any of these areas will generally result in savings. However, changing them in conjunction, by requiring students to walk to school if they live within 2 miles of the school, while placing neighborhood stops that are at least 0.2

miles apart from each other, results in the largest savings when considering routes served, miles traveled, and buses used.

As aforementioned, the environment at DPS has changed since the initiation of this study. Nonetheless, the boundaries and neighborhood stops are available for DPS' use within VersaTrans. Due to VersaTrans automation capabilities, DPS now has the tools necessary to execute any of the scenarios presented in this paper.

V. Future work

5.1 Introduction

This chapter discusses future research that can aid school districts to better run their operations.

5.2 Future work

Now that a routing and scheduling methodology is in place for DPS, with the needed neighborhood bus assignments and boundary settings, DPS can implement any of the scenarios presented in this thesis. There are a variety of potential areas that could follow this research. The first extension would come from a more thorough look at the effect of incremental mandatory walking boundaries. Currently, there is a policy in place, though one that is not exclusively followed, that requires students that live within a 2 mile radius of their school to walk. However, there is also a policy that prevents students from walking more than 0.5 miles to their assigned bus stop. Consideration should be given as to what changes would occur with varying walking requirements because there is obviously a contradiction here. DPS is aware that students that travel on buses, on average, most likely spend more of their time traveling than walkers do. However, due to DPS' open enrollment policy, there is also some concern that an increased walking distance requirement would lead parents to choose schools far enough away to guarantee a place for their child on a bus.

A second recommendation for future study would stem from examining the effects associated with different bell schedules. Several charter and nonpublic schools do not follow the same six hour and fifteen minute school day. Hence, a consolidated bell schedule may not make sense. However, a design of experiments in this area might provide great insight and possibly make most of the schools within the district agreeable to a more efficient bell schedule as it relates to efficient routing.

A third area for investigation would be the benefits linked to a mixed versus pure pallet routing scheme. DPS uses a mixture of the two, depending on the proximity of the schools and the number of children that ride between the following. It is assumed that a mixed pallet methodology would provide additional savings, but further research is necessary.

DPS also recognizes that there is absenteeism throughout the district. As a matter of fact, there seem to be many phantom riders in the system, especially from non-DPS schools. DPS will sometimes institute count sheets to determine who is actually riding buses, and it intentionally overfills some of its buses to account for it. By scheduling bus routes which overfill each bus's capacity by a certain percentage, as airline schedulers do, buses can be filled to near capacity by accounting for the students who are scheduled to receive rides but will not utilize that service. However, this is a source of political contention here because if a bus is overfilled, it violates safety rules, which are unacceptable to DPS.

Finally, additional savings may also be found thru using a hub and spoke methodology where schools act as hubs. The hub and spoke methodology elicits some concern in the community due to possible safety issues with the congregation of children,

as well as the inability of younger children to follow transfer instructions. However, with an open enrollment policy, placing key hubs around the district to store and route buses, opposed from a central depot, is a ripe area for investigation.

Appendix A: Charter and Nonpublic Bell Schedules

Charter PK - 8				
7:40 AM - 4:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
DAYTON ACADEMY	0K	8	7:40 AM	4:00 PM
DAYTON VIEW ACA	0K	8	7:40 AM	4:00 PM
7:45 AM - 2:45 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
ACAD DAYTON	0K	8	7:45 AM	2:45 PM
HORIZON ACADEMY	5	12	7:50 AM	2:35 PM
NEW CHOICES	5	8	7:55 AM	2:35 PM
8:00 AM - 2:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
MAIN ST AUTO	8	12	8:00 AM	2:00 PM
8:00 AM - 3:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
ELECT CLASS OF	0K	12	8:00 AM	3:00 PM
HAHONING COUNTY LIMITED	0K	12	8:00 AM	3:00 PM
MORAINE COM	0K	12	8:00 AM	3:00 PM
TRECA	0K	12	8:00 AM	3:00 PM
VIRTUAL COMM	0K	12	8:00 AM	3:00 PM
EAST END COMM	0K	8	8:00 AM	3:05 PM
8:00 AM - 3:15 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
N DAY SCH DISC	0K	8	8:00 AM	3:15 PM
8:00 AM - 4:08 PM				

Bldg Name	From Grade	To Grade	Arrive	Depart
TROTWOOD FIT	0K	8	8:00 AM	4:08 PM
BUCKEYE ON-LINE SCHOOL FOR SUCCESS	0K	12	8:00 AM	4:00 PM
8:05 AM - 3:30 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
NEW CITY SCHOOL	0K	12	8:05 AM	3:30 PM
8:30 AM - 3:05 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
CITY DAY COMMUN	0K	8	8:30 AM	3:05 PM
8:30 AM - 3:41 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
EARLY COLLEGE	7	8	8:30 AM	3:41 PM
8:45 AM - 4:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
EMERSON ACADEMY	0K	8	8:45 AM	4:00 PM
9:00 AM - 4:15 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
NU BETHEL SCH	0K	8	9:00 AM	4:15 PM

Non Public PK - 8				
7:20 AM - 2:30 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
O L ROSARY	0K	8	7:20 AM	2:25 PM
M Q PEACE GRAM	0K	8	7:30 AM	2:30 PM

7:40 AM - 2:30 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
ASCENSION	0K	8	7:40 AM	2:30 PM
M Q PEACE HOMEW	0K	8	7:41 AM	2:30 PM
7:40 AM - 3:45 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
D SCHRISTIAN	0K	8	7:40 AM	3:45 PM
7:45 AM - 2:15 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
ST HELEN	0K	8	7:45 AM	2:15 PM
7:45 AM - 3:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
HILLEL ACADEMY	0K	12	7:45 AM	3:00 PM
HOLY ANGELS	0K	8	7:45 AM	2:50 PM
7:55 AM - 3:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
ST RITA	0K	8	7:45 AM	2:40 PM
IMC	0K	8	7:45 AM	2:45 PM
7:55 AM - 3:00 PM				
Bldg Name	From Grade	To Grade	Arrive	Depart
E D CHRISTIAN	0K	8	7:55 AM	3:00 PM
PRECIOUS BLOOD	0K	8	8:00 AM	2:55 PM

Appendix B: Blue Dart

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SAVING MILLIONS OF DOLLARS FOR AN OHIO SCHOOL DISTRICT

The Air Force Institute of Technology (AFIT) is sharing its knowledge on vehicle routing and scheduling with the local area. A student at AFIT is helping Dayton Public Schools (DPS) take advantage of available Operations Research techniques to minimize, as much as possible, the costs associated with the operation of their pupil transportation system. With rising fuel costs and a deep economic recession looming, it is imperative that school districts across the nation find ways to cut costs in their transportation operations. One of the more likely sources for savings is streamlining and/or consolidating bus routes.

In 2008, DPS took a positive step towards gaining better control of its spending. DPS management identified three major items that needed to be addressed: using proprietary routing optimization software, community involvement, and customer service. It should be of no surprise that door-to-door pickups and deliveries is inefficient compared to neighborhood or “straight line” bus stops. Straight line stops are those placed on main roads that have been designated safe by DPS officials. Considerable

savings will come from parting with the door-to-door student pickup methodology and establishing centralized “ministops” that students must walk to. By using their existing software, an automated school bus routing and scheduling system can not only minimize the transportation costs incurred by the school district in question, but also minimize the average transportation time of each student. Most importantly, it can provide an automated procedure for setting up daily schedules for the fleet (Bodin, 2001).

A second major point to generating savings is by involving community members in any matter that will impact the general public. Doing so ensures that all concerns are addressed by an unbiased group and that no individual faction is inadequately represented. By actively involving this affiliation, the taxes expended on transportation are justified, while securing the safe and efficient transportation to as many of its city pupils as possible.

In an effort to get back to the basics of their operations, DPS school decision makers came together to unearth efficiency improvement opportunities that may exist within its enterprise. They formed a Transportation Community Collaborative that includes a wide range of individuals from the community: the DPS associate superintendant, the director of DPS transportation, principals, teachers, bus drivers and union affiliates, business leaders, and parents.

The biggest hurdle in generating savings for DPS is ensuring that the savings recouped in implementing the new transportation methodology justify any decrease in customer satisfaction that may ensue. It is only natural to conduct a cost assessment using a software package that has not only been verified, validated, and accredited by the transportation community, but is also readily available and understood by DPS routing

staff. For that reason, VersaTrans serves as the primary optimization software package used to develop more efficient routes.

By getting buy-in from the community to go back to neighborhood stops, rather than picking up children from their doorsteps, and returning to a mandatory walking distance for students that live less than 2 miles from their school of choice as is the code in Ohio, DPS can save over 30 buses using its optimization software. With each bus costing between \$50,000 to \$200,000, DPS has the potential to save between \$1,500,000 to \$6,000,000. This is an extraordinary amount of money that can be used for other programs in education to help students remain competitive in this increasingly global community.

Frankie Woods is currently an Operations Research Masters student at the Air Force Institute of Technology.

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14. ABSTRACT <p>The routing and scheduling problem involves both constructing efficient routes to deliver goods or services to and from customers from a single depot or set of depots, as well as scheduling particular vehicles to these routes such that customers receive their goods within a specified time window. There have been several different methods developed to reduce the costs incurred in transporting goods or services (i.e. students) to customers (i.e. schools). This problem may be used to model many circumstances in logistics and public transportation.</p> <p>Several school districts do not utilize operations research techniques to minimize, as much as possible, the costs associated with the operation of its pupil transportation system. In contrast, Dayton Public Schools (DPS) employs the optimization software package VersaTrans to minimize its transportation expenses. However, due to the importance it has placed on customer satisfaction, DPS has ultimately been reduced to door-to-door pickups. This, combined with an open enrollment policy and higher fuel prices, has resulted in an explosion of transportation related costs. Though DPS has made many great strides to gain control of its spending, due primarily to better management, there is still much to accomplish. This thesis seeks to utilize the VersaTrans routing software available to the Dayton Public School district to construct efficient routes that are feasible under a consolidated bell schedule so that both bus usage and route times are minimized</p>				
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